N89-20285

An Expert System Based Intelligent Control Scheme for Space Bioreactors

Ka-Yiu San
Chemical Engineering Department
Rice University, Houston, Texas

Abstract

An expert system based intelligent control scheme is being developed for the effective control and full automation of bioreactor systems in space. The scheme developed will have the capability to capture information from various resources including heuristic information from process researchers and operators. The knowledge base of the expert system should contain enough expertise to perform on-line system identification and thus be able to adapt the controllers accordingly with minimal human supervision.

Introduction and Approach

Mammalian tissue cells are very sensitive to small changes in their growth environment (pH, temperature, nutrient and byproduct concentrations) and thus require precise regulation on reactor parameters. However, the design and implementation of meaningful control strategies are often hindered by the lack of detailed knowledge about the system dynamics (growth kinetics of the tissue cells as an example) and the lack of availability of proper sensors. It is further complicated by the possibility of variations in process characteristics and parameters during the course of operation, such as change in the yield factor of the cells, the number of viable cells and their metabolic activities, etc. Under such situation, the proper tuning of a conventional proportional-integral-derivative controller can become an insurmountable task. This will, in most cases, result in poor reactor performance and possibly may lead to reactor failure. The above scenario clearly dictates the need for the development of a more sophisticated control scheme which is capable : 1) of providing proper control action despite changes in system dynamics, 2) of synthesizing meaningful and effective control strategies under highly uncertain environment, and 3) of integrating heuristic information into existing control algorithms to improve controller performance.

A novel controller design approach is being developed based on the observation that significant improvement in process performance can be achieved by implementing available ad hoc procedures. Most of these ad hoc procedures are in the form of rules that are the results of accumulated experiences and knowledge of the researchers or operators. These rules of thumb are frequently known as heuristics. Unfortunately, existing controller design approaches do not allow easy integration of this type of knowledge representation. We are presently developing an **expert system** which, in our believe, are best suited for the capturing and the utilization of this knowledge to improve controller performance. Expert systems are applications of the new and evolving techniques of Artificial Intelligence. It is a computer program that contains factual, as well as experimental, intuitive, uncertain, and judgemental knowledge. With this knowledge, the program reasons and infers new information to solve problems that are not amenable to algorithmic solutions. In general, an expert system contains three components: a knowledge base, a reasoning mechanism and a control mechanism.

The source of information that are being incorporated into the knowledge base of our expert system includes: 1) existing mathematical process models, 2) operators' and researchers' experiences, 3) experimental data-base, and 4) up-to-date knowledge in cell biology and biochemistry of the process including metabolic pathways, proven or speculative kinetic mechanisms and so on (see figure attached). Furthermore, this knowledge base will be updated by the incoming process measurements. It is through the use of this powerful knowledge base that a meaningful control strategy will be synthesized and implemented.

In summary, the expert system developed herein will contain enough knowledge and expertise that it is capable of performing the tasks of system identification and process controller design with minimal human supervision. In addition, the final version of this control scheme will be a highly intelligent machine which is capable of learning by extracting information from the incoming measurements of the process variables and thus is capable of updating its reasoning pattern in response to changes in process behavior. This is the type of bioreactor control which has the best probability of success for long-term space bioprocessing applications.

Results and Discussion

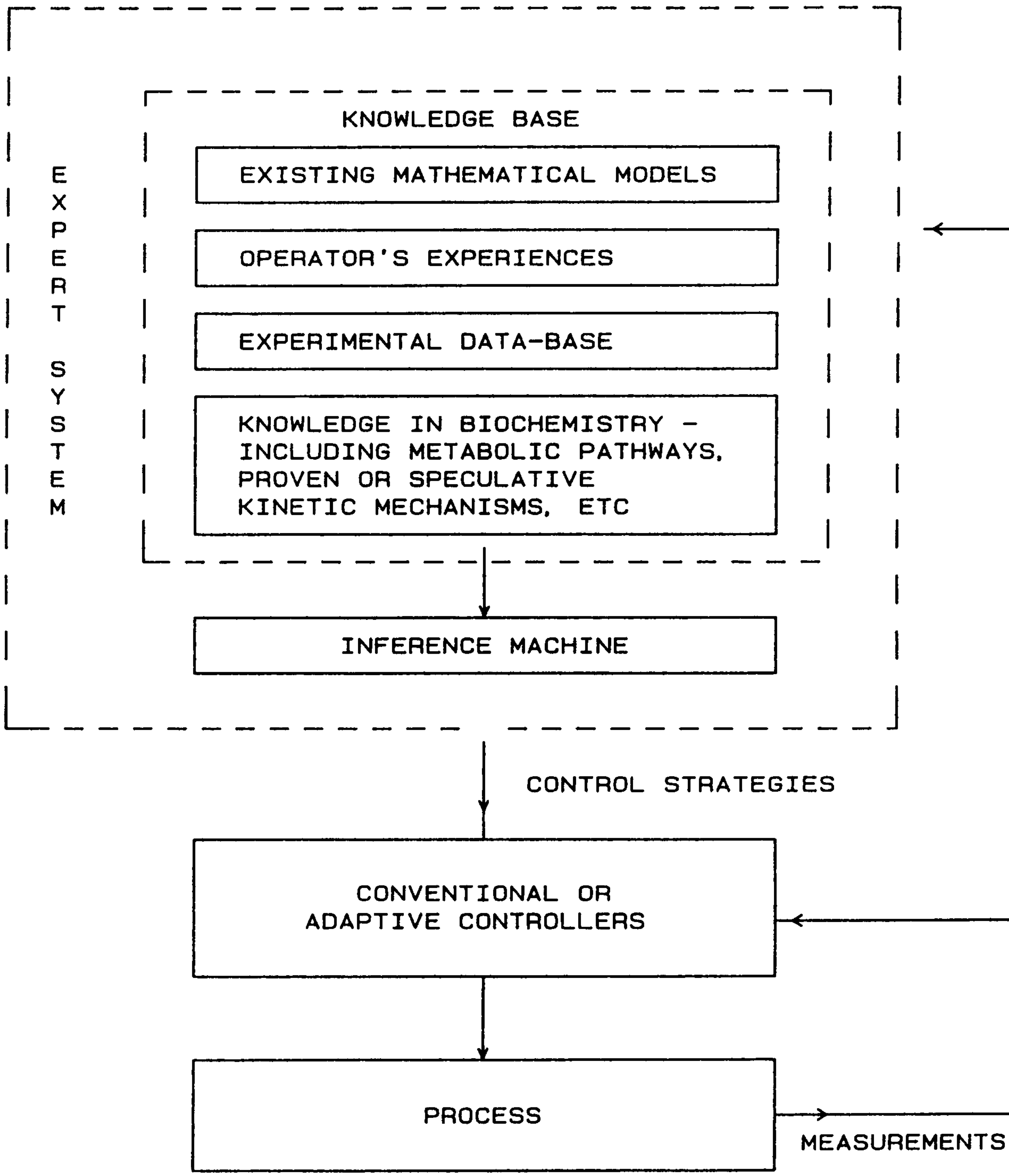
A study aiming at the investigation of the impact of the addition of an expert system to a conventional controller has been performed. Of particular interest is the feasibility of integrating ad hoc heuristic information to the overall control scheme. The control of pH value in a neutralization tank with inlets of different buffering capacities is chosen as a sample system. The set-up of this system is schematically shown in Fig. 1. The reactor pH is controlled by a PID controller which adjusts the flow rate of acid into the tank. Disturbances are introduced by changing the inlet composition according to table 1. The closed loop responses of the reactor pH with two fixed gain controllers tuned for different buffer content and an expert system consulting controller are shown in Fig. 2. The knowledge base of the expert system contains the necessary heuristic information about the process. Table 3 shows the square of the derivations of reactor pH from its set-point for each of the period as well as the total sum. Result from this study can be summarized as follows: 1) In the presence of system dynamic variation, a fixed gain controller may be either too tightly or too loosely tuned which results either in controller instability (middle curve of Fig. 2) or sluggish response (middle part of upper curve), and 2) An expert system based controller is capable of predicting the reactor buffer content and thus is able to select the correct controller setting. This results in a far better controller performance.

In conclusion, results from our studies demonstrate the feasibility as well as the potential of using an expert system to capture heuristic information to improve controller performance. We believe that this approach is capable to provide a fully automated environment with minimal human supervision which is critical for long-term space bioprocessing applications.

The plan for future work in this area is 1) to finish the development of such an expert system, 2) to perform a series of experiments to generate the required knowledge base as well as experiences about the process.

References and Acknowledgement

1. Cardello R. and K.-Y. San, Proceedings of 1987 American Control Conference, June 10-12, Minnesota, to appear.
2. Cardello R. and K.-Y. San, submitted to Biotechnol. Bioeng., (1987)


E X P E R T S Y S T E M
KNOWLEDGE BASE
EXISTING MATHEMATICAL MODELS
OPERATOR'S EXPERIENCES
EXPERIMENTAL DATA-BASE
KNOWLEDGE IN BIOCHEMISTRY - INCLUDING METABOLIC PATHWAYS, PROVEN OR SPECULATIVE KINETIC MECHANISMS, ETC
INFERENCE MACHINE
CONTROL STRATEGIES
CONVENTIONAL OR ADAPTIVE CONTROLLERS
PROCESS
MEASUREMENTS

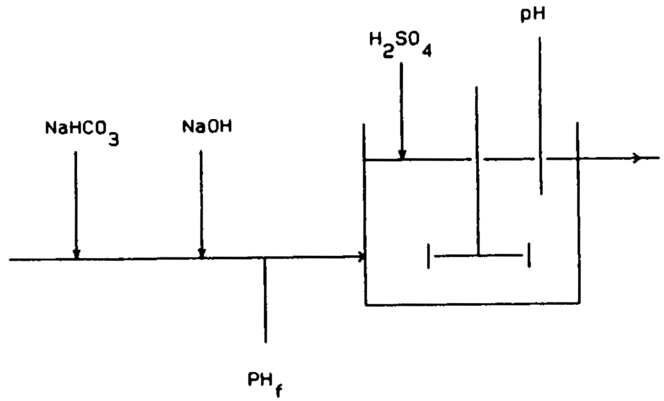


Fig. 1 Schematic of the Neutralization Tank

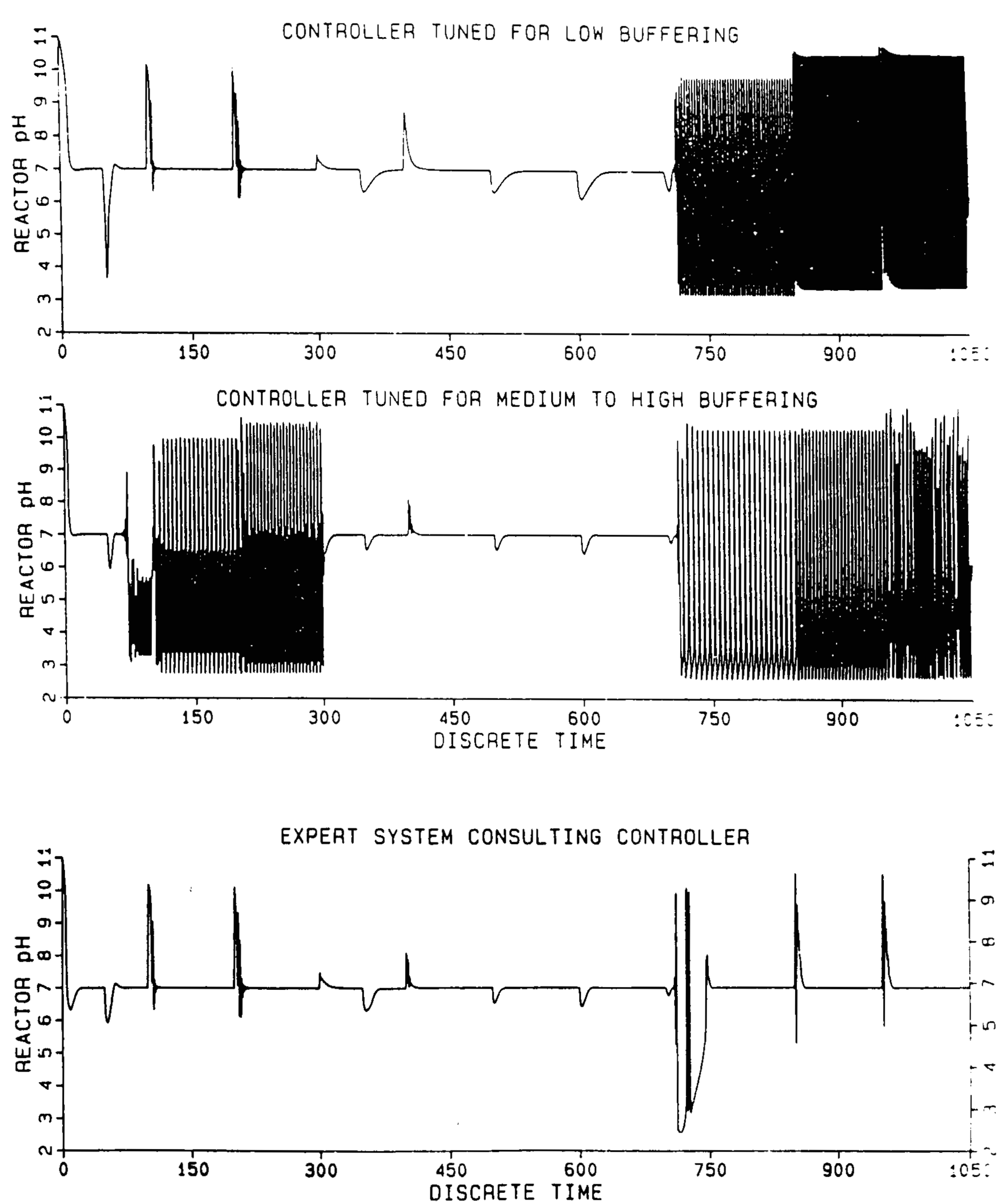
TIME	NaOH CONCENTRATION	NaHCO$_3$ CONCENTRATION	FEED pH
0	0.006	0.006	10.908
50	0.002	0.001	11.042
100	0.006	0.001	11.701
200	0.009	0.001	11.904
300	0.009	0.006	11.509
350	0.006	0.006	10.908
400	0.009	0.006	11.509
500	0.006	0.006	10.908
600	0.002	0.006	9.780
700	0.002	0.0	11.301
850	0.004	0.0	11.602
950	0.006	0.0	11.779

TABLE 1. FEED CONCENTRATION PROFILES

TIME	CONTROLLER TUNED FOR HIGH BUFFER CONTENT	CONTROLLER TUNED FOR LOW BUFFER CONTENT	EXPERT SYSTEM TUNED CONTROLLER
0	47.9	100.3	50.4
50	220.6	36.8	6.1
100	990.3	38.8	38.6
200	1130.4	30.0	30.2
300	19.5	0.6	0.6
350	1.0	4.6	3.9
400	2.2	10.3	2.2
500	1.0	4.6	1.0
600	1.8	8.0	1.8
750	2094.0	1529.3	406.9
850	1538.2	1294.7	29.8
950	1346.0	1290.3	28.6
TOTAL	7392.9	4348.5	600.2

TABLE 2. MEAN SQUARED ERROR FOR VARIOUS CONTROLLERS.

Figure 2



ORIGINAL PAGE IS OF POOR QUALITY